Simulation Study of CO2 Separation Process by Using Hollow Fiber Membrane

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Introduction

In accordance with the Kyoto Protocol and consecutive several international agreements, Korea must prepare for the duty of the reduction of CO_2 emission. Most of the CO_2 absorption/separation processes are energy–consuming so that optimum arrangement of CO_2 absorption system should be acquired through the simulation. In the present investigation, membrane separation process with hollow fiber is simulated to find an optimum design/operation parameter for low energy-consuming one.

The membrane separation of CO_2 requires relative low energy consumption comparing to absorption or distillation type. It can be operated easily and inexpensively since its physical separation mechanism. Also it is suitable to apply in a small-to-medium scale of CO_2 separation process. Therefore, system models for the CO_2 separation process is set up by using the membrane separator then the CO_2 separation process is simulated with changing the parameter of operation condition, separation characteristics by changing the shape of mixed membrane, and etc. The optimum conditions for the CO_2 separation process are obtained by analyzing the design and operation parameters when energy requirement is the lowest.

Methods

Simulation of 1 membrane module is initially made by using the FORTRAN program. After that using these results, 4 bundles of membrane module connected with cascade type is also simulated. During the simulation, operation/design parameters are calculated such as required membrane area, number of modules, permeated CO_2 concentration and the amount of permeated gas with no recycle streams. Finally, recycle mode of membrane simulation is proceeded by using the FORTRAN.

Simulation for 1 module. Simulation of 1 membrane module is conducted with the overall material balance equation is below:

$$(\alpha-1)y_i^2+\left(1-\alpha-\frac{1}{R}-\frac{x(\alpha-1)}{R}\right)y_i+\frac{\alpha x}{R}=0 \qquad \cdots(1)$$

$$A=\frac{(Vy)_{out}}{(J_A)_{out}}=\frac{(Vy)_{out}}{Q_A(P_1x-P_2y_i)_{ave}}$$
$$=\frac{(Vy)_{out}}{Permeate\ flux\times(x-Ry_i)_{ave}} \qquad \cdots(2)$$

α : selectivity
x : Feed composition
y_i: Permeate composition
P_1: Feed Pressure
P_2: Permeate Pressure
R : Pressure ratio(P_2/P_1)
V : Permeate rate

Flow diagram of 1 membrane module simulation is illustrated in **Figure.1**. Several parameters such as operating pressure are varied during the simulation as in **Table. 1**. Different methods of simulation are utilized in the current study. One method is fixing x_t for 0.01, in which x_t represents the retentate composition of CO_2. Then it is calculated that required membrane area, number of required modules, flow rate, and CO_2 concentration of permeate. Another method is fixing number of total modules as 50, then flow rate, CO_2 concentration of permeate, and x_t are calculated.

Table 1. Input Parameters

parameter	amount	parameter	amount
P_1	6 atm	No of HF per module	5000
P_2	0.1 atm	Feed rate	1000 m^3/day
Selectivity	20	Length of HF	50 cm
Permeability	20	Pressure ratio	P_2/ P_1

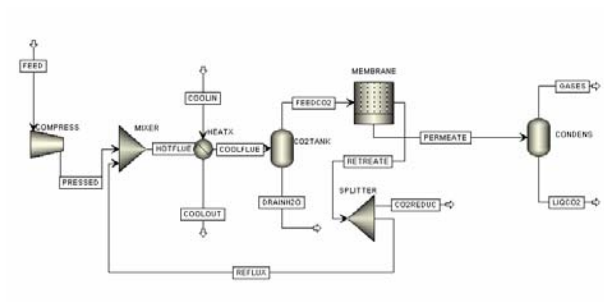

Figure 1. Overall Flow diagram

Simulation for 4 bundles of membrane without recycles. Flow diagram of 4 bundles of membrane module is composed like a cascade in **Figure. 2**. From the simulation, calculated results are illustrated as required membrane area, number of required modules for each bundles, total required membrane area, flow rate and CO_2 concentration of permeate with no recycle streams.

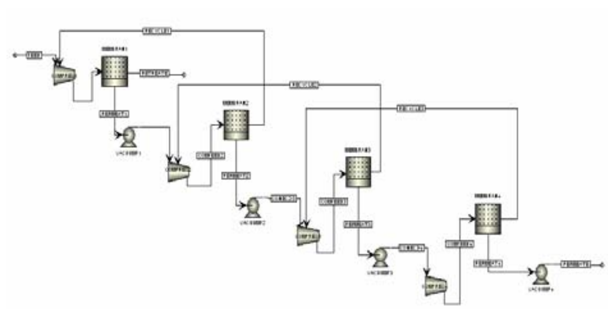

Figure 2. 4 bundles of membrane

Simulation for 4 bundles of membrane with recycles. Simulation with recycle streams is conducted as below. Since the simulation is 4 bundles of membrane module with recycles, calculation is iterated 10 times. It is calculated that required membrane area, number of required modules for each bundle, total required membrane area, number of total required module, flow rate, and CO_2 concentration of permeate.

Results and Discussion

Simulation for 1 module

1. Fixing x_t for 0.01

The result is below in **Table. 2**:

Table 2. Result at fixing x_t for 0.01

parameter	amount
Required membrane area	241.016 m^2
No of required modules	76.72 77
Flow rate of permeate	10.144 m^3/hr
CO_2 concentration of permeate	37.967 %

It is simulated during changing the pressure.

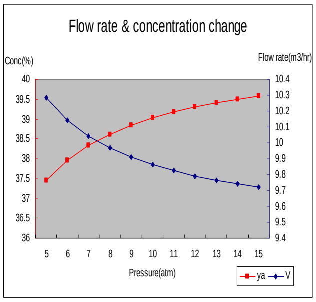

Figure 3. Flow rate & CO_2 concentration change

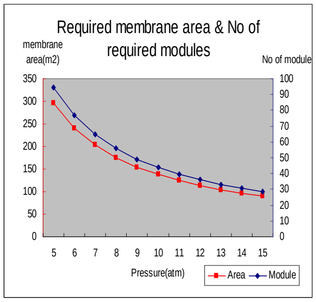

Figure 4. Required membrane area & No of required modules

2. Fixing No of modules for 50

The result is below in **Table. 3**:

Table 3. Result at fixing No of modules for 50

parameter	amount
Flow rate of permeate	6.202 m^3/hr
CO_2 concentration of permeate	48.467 %
x_t	0.0327

It is simulated during changing the No of modules.

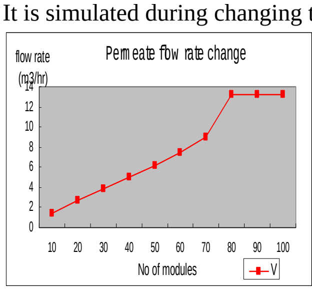

Figure 5. Permeate flow rate change

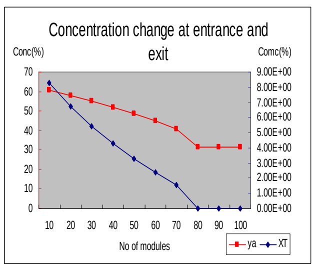

Figure 6. Concentration change at entrance & exit

Simulation for 4 bundles of membrane without recycles. It is calculated that required membrane area & No required of modules for each bundle, total required membrane area & No of required module and flow rate & CO_2 concentration of permeate with no recycles.

Table 3. Result of 4 bundles of membrane without recycles

Parameter	amount
Required membrane area(1stage)	237.016 m^2
No of required modules(1stage)	75.49 76
Required membrane area(2stage)	53.795 m^2
No of required modules(2stage)	17.12 18
Required membrane area(3stage)	22.884 m^2
No of required modules(3stage)	7.28 8
Required membrane area(4stage)	16.018 m^2
No of required modules(4stage)	5.10 6
Required membrane area(total)	329.857 m^2
No of required modules(total)	108
No of required HF(total)	540000
Feed flow rate	41.667 m^3/hr
Flow rate of permeate	2.4718 m^3/hr
CO_2 concentration of permeate	93.329 %

Simulation for 4 bundles of membrane with recycles. It is calculated that required membrane area & No required of modules for each bundle, total required membrane area & No of required module and flow rate & CO_2 concentration of permeate with recycles.

Parameter	amount
Required membrane area(1stage)	275.448 m^2
No of required modules(1stage)	87.68 88
Required membrane area(2stage)	50.111 m^2
No of required modules(2stage)	15.95 16
Required membrane area(3stage)	17.660 m^2
No of required modules(3stage)	5.62 6
Required membrane area(4stage)	10.107 m^2
No of required modules(4stage)	3.22 4
Required membrane area(total)	353.326 m^2
No of required modules(total)	114
No of required HF(total)	570000
Feed flow rate	41.667 m^3/hr
Flow rate of permeate	2.8708 m^3/hr
CO_2 concentration of permeate	93.866 %

Table 4. Result of 4 bundles of membrane with recycles

Calculation is iterated 10 times. The result is below in **Figure. 7** & **Figure. 8**.

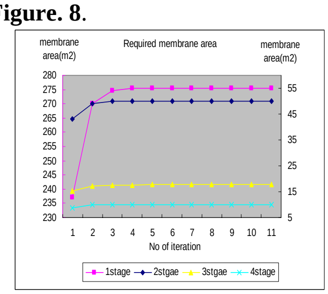

Figure 7. Required membrane area

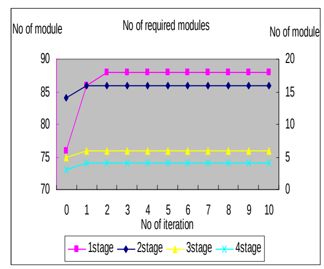

Figure 8. No of modules

Conclusions

When there are recycles, flow rate & CO_2 concentration of permeate are increased about 0.4m^3/hr and 0.53%. Required membrane area & No of required modules at 1st stage are increased. But, required membrane area & No of required modules at other stage are decreased. Total required membrane area & total No of required modules is increased. Total No of required modules is increased about 6 modules.

These results indicate that we can remove more CO_2 and get the high CO_2 concentration. If more bundles are attached, the separation units by using the hollow fiber membrane remove more CO_2 and get the high CO_2 concentration. Therefore, it is very useful that CO_2 separation process by using the hollow fiber membrane.

References

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